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Students' Experimental Research Competences in the Study of Physics

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ABSTRACT

The actuality of the investigated problem is caused by the need for students' training at pedagogical high schools to meet the challenges of research activities and the insufficient development of the theoretical, content-technological, scientific and methodological aspects of the formation of their experimental research competencies at the undergraduate level, in particular, within the framework of laboratory course on general physics. The purpose of the article is to identify the most appropriate ways to form experimental research competencies during the laboratory course. The study revealed that the organization of mini investigations within the laboratory works on physics contributes to the formation of experimental research competencies of undergraduate students at pedagogical universities. Results of the investigation can be used in higher education establishments, Institutions of Advanced Training of Teachers of Physics and Physical experts in secondary schools and colleges.

KEYWORDS
Experimental research competence, students of physics, pedagogical university, general course of physics, mini investigations

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Introduction

The purpose of the higher education in the Republic of Kazakhstan is training of professionals who will have the broad-based knowledge, a deep understanding of the basic tendencies of development of modern science, techniques and technologies, who can participate in the process of modernization of the country's economy. This is due to the increase in scientific and technical information; automation of production and the introduction of flexible technologies enabling to quickly and efficiently rebuild the existing production capacity for the manufacture of new products; national implementation of national innovation projects; the need for scientific research of major problems.

In terms of new requirements to a specialist – a high level of intellectual abilities, research way of thinking, creative activity, the ability to quickly perceive and respond to changes in science and industry –the objectives of modern higher education are specified.

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The main task of high school becomes not only training targeted specialists for a particular area of activity, but the development of the personality of each individual, expansion of his/her professional and research competencies as well (Berdi et.al., 2015).

Experimental research competency of a Bachelor of Science in Physics can be defined as the ability and willingness of the individual to independently and effectively carry out experimental research, to forecast its results and to put them into practice. Future physicists are permanently confronted with complex non-standard situations in their professional activities. Moreover, they design and create them on their own. Research activity, by which experimental research competency is formed, is the basis of professional work of the future expert. In our opinion, experimental research competency for pedagogical high school student in the study of physics is the basis for the formation of professional competence.

Requirements to key competencies of BA in Specialty 5B011000 – Physics; core competencies for graduate level education have been developed. To solve professional problems a Bachelor of Science in Physics is to aquire the following skills:

- develop scholarly apparatus of research; use different methods of psychological and educational research;
- organize and carry out research work in physics;
- process and evaluate the results of the research work; generalize and draw conclusions based on the results of research (2012, Compulsory Educational Standard of the Republic of Kazakhstan).

For this study, important is an issue related to the management of learning and research activities of undergraduate students.

High professionalism of an individual in a particular area depends a lot on the degree of formedness of his/her research competency (Mji and Makgato, 2006). However, in psychological and pedagogical literature an issue of formation of competencies of students studying physics at the undergraduate courses is downplayed. However, practice shows that the readiness of the majority of seniors who start research work leaves much to be desired. Therefore, the formation of experimental research competencies from the very first years of study is one of the urgent problems of higher education, and creative work should be introduced in all disciplines, including the labs of general practical physics in the general physics course. Issues of creating methodological training systems in general physics have been studied by Zacharia, Z. C. (2007), Guisasola (2004), Naven Chetty (2015) and others.

Abroad many universities pay great attention to the development of student competencies, including physics students (Jones, 2003; Wieman and Perkins, 2005; Module Description. Department: Physics. Discovery Skills in Physics, 2016; Carey, 2015; Holmes et al., 2015; Lederman and Abell, 2015; Rauch et al., 2014; Tugulea et al., 2011). It is indicated that at graduation fundamental competencies of physics majors are “knowledge-based, performance/skills-based, and affective” (Goals of the Physics Major, 2016). In order to acquire better results and to improve the effectiveness of learning and teaching, a new paradigm has being developed, which makes shift from a professor-centred to a student-centred approach (Jones, 2003). As distinguished from traditional approach which stresses the content in the program design, it aims to develop students’ creative

abilities by giving them more scope for problem-solving, team work, collaborative learning (Jones;2003; Msoka et al., 2015) etc. As surveys show, these competencies are considered crucial both by students and by employers (Jones, 2003).

Various teaching techniques are employed to get better learning outcomes and to motivate students in the process of study. Involvement of students in their own learning has certain specifics when speaking of physics students.

Conducting science experiments in laboratories is an appropriate way to develop students' ability to apply knowledge in practical situations, their capacity to learn, critical and self-critical abilities (Jones, 2003; Msoka et al., 2015; Chiaverina and Vollmer, 2005; Vogel, 2011). Experiments are used in physics as the vehicle to develop basic experimental and key skills necessary for physicists (Module Description. Department: Physics Discovery Skills in Physics, 2016). Multimedia design may be relevant to give the student full control over the experiment (Chien and Chang, 2011; Aloraini, 2012; Lin and Atkinson, 2011; Lwoga, 2012; Peeraer, 2010). Another way to promote students' critical thinking is encouraging them to make decisions relating to data collected during their laboratory classes (Carey, 2015). That was the conclusion drawn by physicists at Stanford and the University of British Columbia. Especially it is important for undergraduates who take introductory lab courses during which they usually passively observe their teachers performing experiments following step-by-step instructions. This way of conducting lab classes only helps confirm information presented in textbooks. In order not to refer to lab courses as "primarily "cookbook" exercises" (Carey, 2015), students had repeated practice in making decisions based on data, with feedback on those decisions (Holmes, 2015).

Active learning in laboratory classes may include "solving other more complex problems that may be considered extensions of the material proposed in the class. (ex: after studying an LC circuit they are encouraged to solve the problem of coupled LC circuits and think about the problem of impedance adaptation in a transmission line)" (Jones, 2003).

As practice shows, the traditional method of conducting laboratory studies with the use of ready-made methodology guidelines leads to the fact that by working on a common template, students, strictly following the instructions, can safely perform the work, being not fully aware of the essence of the experiment conducted. At the same time the experimental research competence is not formed and the creativity is not developed in them.

Reasonable combination of traditional methods of conducting the workshop with new approaches will not only allow acquiring basic skills of experimentation, almost master the most important methods of measurement, but also to form the research competency of students studying physics at the undergraduate courses (Usembayeva et al., 2015).

Materials and Methods

Research methods

The study used the following methods: a theoretical analysis of the object and the problem of the research based on the study of official documents, pedagogical and methodological works of domestic and foreign authors; comparison and collation analysis, synthesis, systemization, classification of the literature on the

problem of research; empirical methods: monitoring, organizing and carrying out pedagogical experiment.

Experimental research base

Experimental research base was Kh.Yasavi International Kazakh-Turkish University.

Stages of research

Stage 1 (2014-2015) – verifying stage: study and theoretical analysis, determining of targets, specification of objectives of the study. Development of methodological apparatus, experimental materials for experimental work.

Stage 2 (2015-2016) – search stage of the experiment: development of diagnostics of formedness of research competencies; development, testing and refinement of content, tools, and techniques of mini investigation conducted within laboratory works on physics during the pedagogical experiment.

Stage 3 (2014-2016) – teaching stage of the experiment: analysis, interpretation, systematization and generalization of the findings, clarifying provisions and conclusions, presentation of results obtained in the study.

In the process of studying students' experimental research competencies, we took into account the fact that by this time in school and in the first year at university a certain level of experimental and research skills was already formed. The measurement of this level, as well as its change during pedagogical experiment should be carried out on the basis of the established indicators. In our opinion, the best was distinguishing of three levels of formation of research competencies: "low", "medium" and "high".

In our case it is required to give students such experimental tasks that would make them undertake feasible creative efforts.

Training manuals "Workshop on general physics", "Guidelines for the implementation of tasks for students' independent work under control in the course of general physics" have been developed which are the components of General Course of Physics Training Package.

Physics workshop is designed to help students to be more aware of the basic physical laws and to acquire basic skills of experimentation. In each lab, a workshop is provided by guidelines describing in detail student's step-by-step actions. This common method of carrying out the laboratory work gives a definite result and it cannot be completely eliminated.

However in order to form students' experimental research competencies on the theme of each laboratory work, as well as the previously learnt topics at the first course, creative tasks were developed (for mini investigations), presented in the methodological guidelines for the implementation of tasks for students' independent work under control. In developing tasks, the ideas taken from different methodological and popular scientific literature, as well as those resulting from the authors teaching and research and the research work were used. The main purpose of creative tasks is the development of experimental research competencies of all undergraduate students regardless of their abilities. Creative tasks were designed for three levels of difficulty.

Tasks of the first level are most difficult. They only specify the problem. For the tasks of the second level the problem remains the same, but the wording is

changed so that it contains clues: range of devices and materials is limited; various ways for the assignment performance are outlined.

The third level of assignments is maximally simplified, its formulation contains more tips, but the creativity elements are still present in it. The individual tasks are provided with assistance card (creative tips) containing a pre-arranged question, a scheme, a pattern, a formula, and so on. Cards are gradually narrowing down potentialities to find a solution, but do not give a direct answer.

The effectiveness of the developed method of formation of students' research competencies in the framework of the laboratory workshop was revealed in the course of pedagogical experiment. The experiment was conducted at the Faculty of Natural Sciences of A.Yasavi International Kazakh-Turkish University and Kyzylorda State University named after Korkyt in 2014-2016. Educational experiment was conducted in three stages: ascertaining experiment; search experiment; formative experiment. At different stages 116 students participated in the educational experiment.

Results

During the ascertaining pedagogical experiment the following methods were mainly used: attendance of laboratory classes and the core course units, the interlocution with leading educators, filling in the diagnostic charts and charts of the student's self-development, holding mid-term quizzes.

To determine the level of formedness of students' experimental research competencies the diagnostic tasks were developed, the wording of which is divided into three levels. The tasks of the first level are most difficult. They only define the problem.

For the tasks of the second level the problem is the same, but the wording is changed so that it contains tips.

The third level contains maximally simplified tasks, its formulations contain more tips, but there are still creativity elements in it. Some tasks are provided with assistance cards (indirect clues). While drawing up diagnostic tasks different methodological literature and ideas resulting from our educational, research and scientific-research activities were used. The following requirements were specified for the tasks: the availability of this stage of training for the students, equivalence of options, availability of instruments and materials when performing tasks, availability of the required literature, ease in carrying out experiments, the ability to perform the work for one session (80 minutes).

The basis of the division into three levels of formedness of experimental research competencies is the degree of autonomy in performing diagnostic tasks.

High level means that a student independently performs the creative task of the first level of complexity; the assistance cards are not used to do it.

Mid level denotes that a student fulfills the task of the second level of complexity and uses one or two assistance cards.

Low level presupposes that a student performs the task of the third level of difficulty; and in this case more than two cards are used. Students' work was examined both by the teachers teaching the core courses and those who hold laboratory classes. The purpose of the double assessment is to reduce the possibility of subjectivity in the evaluation of the level of formedness of research competencies.

The control and experimental groups (CG and EG) included the same number of students. The results of incoming test hold by the students of the 2nd year of studies in the experimental and control groups are shown in Table 1.

Table 1. The level of formedness of physics student research competencies according to the results of incoming test

	The level of formedness of research competencies, %					
Levels	**I level**		**II level**		**III level**	
№ task	**CG**	**EG**	**CG**	**EG**	**CG**	**EG**
1	10.3	8.6	39.5	40.6	50.2	50.8
2	9.5	9.7	44.5	47.2	46	43.1
3	11.3	10.7	53.2	57.3	35.5	32
4	9.2	9.5	49.5	39.4	41.3	51.1
5	8.7	8.8	45.8	43.8	45.5	47.4
6	12.3	13.3	51	52.3	36.7	34.4

To evaluate the results of the formation of experimental research competencies of students-physicists, the criterion χ^2 was used that allows us to compare not the absolute average values of some variables before and after the experiment, but the percentage distribution of data. The criterion enables to check the null hypothesis about the reliability of coincidence of the initial level of formedness of research competencies in the experimental and control groups.

The critical value of the criterion $\chi^2 = 5.99$ for the significance level of $p = 0.05$ and the number of degrees of freedom $v = 2$. Thus, $\chi^2_{emp} < \chi^2_{cr}$, hence the difference in the results of the experimental and control groups was not statistically significant at the initial stage of the experiment. Prior to the experiment, statistically significant differences were not found between the control and experimental groups of students.

The second stage of this study, in which creative tasks for mini investigations were made, the necessary physical equipment and materials were selected, a technique of formation of research competencies within the laboratory classes and necessary teaching material were developed, was completed with the searching pedagogical experiment.

Searching pedagogical experiment was carried out to clarify the suggested hypothesis, the choice of effective methods, forms and means of formation of research competencies and search for the optimal diagnostics of research competencies.

During the search experiment the following tasks were solved:

- clarification of the role, place and didactic opportunities of lab classes in the formation of research competencies;
- testing and validation of the creative tasks designed for mini investigations, specifying methods and techniques of their implementation;
- identifying drawbacks of the developed guidelines;
- selection and verification of the effectiveness of diagnostics of formation of different levels of research competencies.

Level of formation of students' research competencies was determined by the results of a series of assessment tests, survey analysis and assessment at special seminars.

Students filled in designed diagnostic cards of the formedness of Bachelor physicist's research competencies. The relationship between research competencies and indicators of their formedness was set using Spearman rank-order correlation coefficient. Grades given by teachers were processed using χ^2 criterion. The data obtained were applied to construct bar graphs. As a result of the searching pedagogical experiment the modification of creative tasks for mini investigations, of methodologies and guidelines for their implementation was performed.

The next stage of our research was formative pedagogical experiment, which aimed to confirm the hypothesis of the study. The experiment lasted four years, from 2006 to 2010. During the formative experiment the following task was solved: to check the effectiveness of the developed method of formation of physics students' research competencies at the undergraduate level at the laboratory classes (using mini investigations).

Levels of formedness of research competencies of physics students of the first years of study were determined by the results of a series of assessment tests, surveys, seminars, analysis of diagnostic cards. The results of an assessment test conducted after the experiment with the participation of physics students of the 2 year of study, is presented in Table 2.

Table 2. Level of formedness of physics student research competencies after the experiment

	Level of formedness of research competencies, %					
Level	**I level**		**II level**		**III level**	
№ task	**CG**	**EG**	**CG**	**EG**	**CG**	**EG**
1	15.7	18.1	41.5	48.6	42.8	33.3
2	13.5	16	49.7	57.2	36.8	26.8
3	18.4	21.8	57.6	66.3	24	11.9
4	12.9	15.2	51.5	59.5	35.6	25.3
5	18.2	21.8	55.8	65.8	26	12.4
6	15.6	18.3	59	68.6	25.4	13.1

Data obtained by calculating the criterion are shown in Table 3.

Table 3. χ^2 criterion value

Task №	Criterion value
1	6.25
2	6.33
3	6.1
4	6.13
5	6.12
6	6.17

Statistical processing of the assessment test conducted at the control stage of pedagogical experiment resulted in obtaining the value χ^2- criterion equal to 6.18. Since $\chi^2_{emp} > \chi^2_{cr}$, the results obtained during the experiment show significant

differences between the samples, i.e., the proposed method improves the level of formedness of students' research competencies.

The findings obtained allow concluding that the experimental group shows a higher level of formedness of Bachelor physicist research competencies in further education as compared to the control group.

Repeating comparative diagnostics several times, which resulted in similar findings, enhances their reliability.

Discussions

The obtained analysis of the results showed that the students enrolled in the experimental group, demonstrated much better results of tests determining the level of acquiring knowledge than the results of students in the control groups. Thus, the findings of the pedagogical experiment confirmed the suggested hypothesis of research and identified possible ways to improve the process of forming experimental research competencies of students studying physics at the undergraduate level:

- to continue the work on the introduction of modern methods of research into all academic studies, including practical physics;

- to increase the students' creative activity in the process of learning general physics;

- to ensure the thematic unity of learning and research and scientific-research work of students at different courses.

In the course of pedagogical experiment, its main tasks have been solved. The analysis of process and experimental results leads to the following conclusions:

1. The experiment confirmed the effectiveness of the proposed method of formation of experimental research competencies of undergraduate students within the laboratory works on general physics (using mini investigations).

2. The experiment conducted with the participation of students of Specialty 5B011000 – Physics showed that even a partial realization of the developed approaches in the formation of experimental research competencies can significantly improve the level of formedness of experimental research competencies.

In the course of pedagogical experiment the possibility of the transfer of the developed system of formation of experimental research competencies in training students of Specialty 5B011000 – Physics has been revealed, as well as the possibility of partial use of the developed materials within the traditional system of higher education.

The undertaken pedagogical experiment confirmed the effectiveness of the developed method of formation of experimental research competencies of students in the framework of laboratory course on general physics.

Conclusion

Theoretical and experimental study on the formation of experimental research competencies of students in the study of general physics course confirmed the suggested hypothesis and allowed solving all set tasks.

A new paradigm demonstrating the shift to a student-centered approach helps motivate students in the process of study; it presupposes students'

involvement in their own learning. Carrying out laboratory experiments is of great importance in developing students' critical and self-critical abilities; the creativity is developed in them, when they do not strictly follow instructions but make conclusions on their own at a certain stage of their experimental work at a laboratory.

Experimental research competencies of undergraduate students studying general physics as a special property of the person representing a balanced mix of sustained motivation to conducting physics research and the ability to perform research work with the use of physical methods, is worth forming using mini investigations within the laboratory course on general physics.

The organization of such mini investigations increases the level of formedness of experimental research competencies of undergraduate students and prepares them for independent research at senior university courses. As a result, it increases the level of formedness of the experimental research competencies of graduates in pedagogical institution. It has been found that this teaching technique develops interest in physics, leads to its deeper understanding, improves the quality of knowledge making a positive impact on the process of their formation and promotes the use of knowledge for solving application tasks in various branches of knowledge.

Disclosure statement

No potential conflict of interest was reported by the authors.

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